Metrology Education Including GD&T in Engineering Technology

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Abstract

While engineering programs tend to focus on theory, engineering technology programs like those at Purdue Polytechnic Columbus focus on practical and applied concepts related to manufacturing which includes standardized drawings and Geometric Dimensioning &Tolerancing (GD&T). This paper introduces how metrology and GD&T are adopted in the classroom work and how hands-on activities are integrated to reinforce the learning of these critical manufacturing topics. 3-D printing is employed to create relevant objects to measure that highlight the concepts studied in the classroom. Similarly, students are assigned a reverse engineering project that includes making measurements, creating a standards-based drawing with GD&T specifications, 3-D printing the part and then measuring the part for both dimensions and geometric quantities like circularity, cylindricity, parallelism and perpendicularity. Some of these artifacts will be demonstrated during the presentation. An environmentally-controlled metrology lab that is maintained at ISO standards is employed during the course activities. Additionally, the lab has measurement tools including a Coordinate Measuring Machine (CMM), roundness tester, surface finish tester, an Instron tensile tester, and numerous hand tools among other items. These outstanding facilities have been utilized throughout the Mechanical Engineering Technology curriculum but are emphasized in a class that focuses on production specifications, which also addresses (GD&T).

Introduction

An environmentally-controlled metrology laboratory that resulted from a partnership between Purdue Polytechnic Columbus, a local non-profit organization, and a manufacturer, is used throughout the engineering technology curriculum to reinforce the necessity of controlling the environment to obtain useful measurement information. Temperature is the largest contributor to errors in dimensional metrology and a lab controlled at 20°C ± 0.5°C with humidity below 50% is the most effective way to eliminate these errors. The collaborative partnership that created the lab evolved from a six-sigma study conducted by the industry partner, focusing on metrology skills [1] and is discussed in more detail in the work by Stahley, et al. Other courses have been developed by the author and more information on those courses can be found from an additional paper [2].

Class in Production Design and Specification

The class utilized to introduce measurement and GD&T focuses on production design and specification. The course description is

The design, evaluation, and documentation of engineering specifications required for manufacturability and assembly are introduced. Emphasis is on CAD-based details, assemblies, design layouts, equipment installations and related industrial practices.

Two of the outcomes desired for this class are

1. *Apply American National Standard drawing techniques unique to various specialty industrial manufacturing processes, in the production and interpretation of engineering drawings.*
2. *Follow current American National Standards practices in generating a complete assembly/detail dimensioned set of drawings, given design intent and a mechanical design.*

There is much emphasis in the class on the production and interpretation of industrial drawings, including GD&T specifications. Many graduates of Purdue Polytechnic Columbus are employed by local manufacturing companies in production and quality engineering roles. Engineering Technology students who complete this class and others at the institution are ready to contribute to those companies in those roles when they are hired. They basically “hit the ground running”. Other employees with engineering backgrounds are not capable of this immediate contribution to the company and require training programs to understand drawings, tolerancing, geometric dimensioning, and the manufacturing process.

Classroom Activities

At this point in their learning, students have acquired 3-D modelling skills using one of the popular software tools. However, they have had little experience in creating drawings and understanding the basics of dimensioning, standards, and geometric dimensioning and tolerancing. Fortunately, the same software tools make this a relatively easy process compared to actually creating drawings on a drafting table. Students are introduced to dimensioning rules as specified by ASME Y14.5-2009 and are assigned parts (using drawings of the parts) to create using 3D modelling and also produce drawings that follow the standards, including GD&T. While students may not quite understand the specifics of the GD&T callouts, they learn the mechanics of including datum planes, basic dimensions, tolerances, feature control frames, and the various symbols required.

After nearly a month of these activities and assignments, GD&T is introduced and utilizes the book by Krulikowski[1], which in the first few chapters, emphasizes drawing standards, tolerances, and dimensioning symbols and provides a useful review of those topics. The remainder of the semester focuses on the datum system and form, orientation, position, and runout geometric tolerances. The current manufacturing base in the area includes a significant amount of rotating equipment so the runout geometric tolerance is incorporated in the class. At this point, the class with the material presented has been a classroom, academic pursuit with no real lab or hands-on activities.

Measurement Activities

Purdue Polytechnic Columbus, with the available measurement equipment, is in a unique position to add significant, relevant measurement activities to the curriculum as well as offer non-credit training programs supported by that equipment. As a final project in this class, students are required to first create a 3D model and drawing of the part shown in Figure 1. For this class, the CAD tool employed was Autodesk Inventor but the institution has recently switched to using SolidWorks. Figure 2 lists the requirements of the assignment. Students are asked to build a 3D CAD model of the part and also produce a drawing that re-creates the drawing in Figure 1, including all the dimensions, datums, and geometric dimensioning and tolerancing specifications. After creating the 3D model and drawing, a stereolithography file is exported from the CAD program and is used as the input to the 3D printing process. The 3D print zone of the institution has many different materials available so the lab manager chooses different materials for each print to provide a comparison of geometric properties with the various materials.

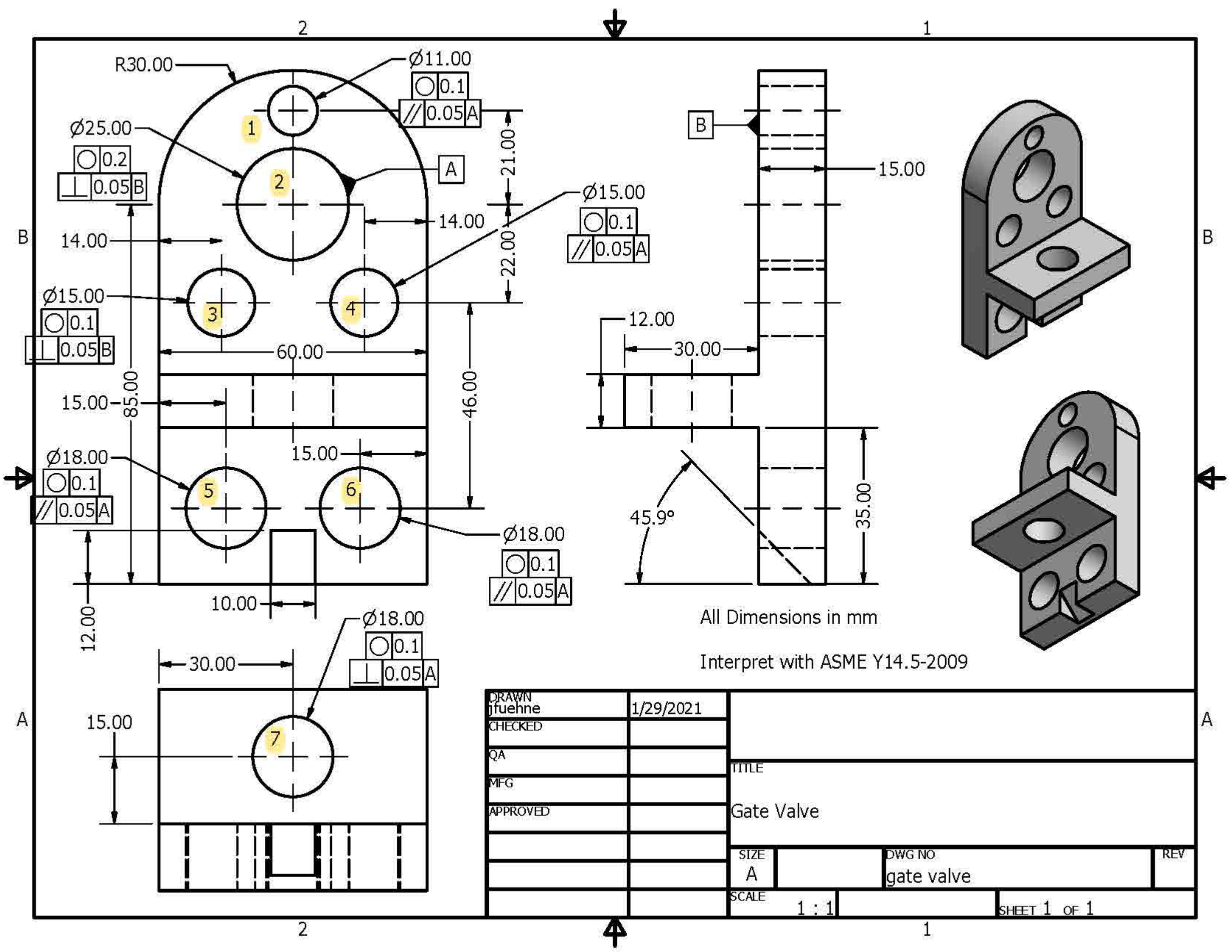

Figure 1. The part utilized in the final project of the GD&T class.

Final Project
GD&T Measurements

Objective

The purpose of this final project is to execute measurement of geometric tolerances on a Coordinate Measuring Machine (CMM) to evaluate the precision of 3D printing a part.

Procedure

1. Create the part in a CAD software tool.
2. Export a .stl file using "high" resolution.
3. Send the part electronically to the measurement center for 3D printing.
4. Once printed, use the specified tool to measure the dimensions of the part.
5. Utilize the CMM to measure the Geometric Dimensioning and Tolerancing specifications and the 21 mm, 22 mm, and 46 mm diameter dimensions on the attached drawing.
6. Summarize the project with an Executive Summary Lab Report. Format and template are attached.
7. Include in your report the following:
   a. Table comparing nominal dimensions to dimensions measured
   b. Table similar to attached table that evaluates the 3D printed gate valve using the CMM results – hole diameters, circularity measurements, parallelism or perpendicularity measurements, and the hole center-to-hole center dimensions specified in the table.
   c. Bar graph that compares the actual circularity measurements of the 7 holes.
   d. Bar graph comparing the 3 parallelism measurements.
   e. Bar graph comparing the 4 perpendicularity measurements.
   f. Bar graph comparing the actual diameter measurements of the 7 holes.
8. The report should have 7 attachments:
   a. Your drawing of the gate valve.
   b. 2 tables
   c. 4 bar graphs.
9. The text of the Executive Summary Lab Report should be limited to 1 page and should include a paragraph on the objectives/procedures, a paragraph on the results, and a paragraph for the conclusions.
10. Conclusions should address the precision of your gate valve 3D printed part with particular attention paid to hole #7, which is printed 90 degrees to the other 6 holes. (See attached drawing for hole numbers). Also, consider the two sets of identical side-by-side holes (3 and 4, 5 and 6) and also potential differences in precision related to the size of the hole (11mm vs 25mm).
11. Your report should have 9 pages – the rubric sheet as the first page, the text as the second page, and then the 7 attachments.

Figure 2. The details of the final project to measure GD&T specifications.

After receiving the printed part, students are required to completely measure the part and to accomplish this with different measurement tools. As part of the final report to be submitted, a table is required which compares the measured dimensions to the nominal dimensions and would be similar to Table 1, which also specifies which dimensional tool is to be used for the measurements. For reference, Figure 3 displays the dimension letter on the drawing so that students can accurately complete the table and the proper measurement and then compute the percent difference.

As seen in Table 1 and Figure 3, most diameters are to be measured with a bore micrometer, but some diameters are to be measured with a Vernier caliper to highlight the differences in resolution and technique between these tools. In particular, students

Table 1. Spreadsheet table example for documenting the measured dimensions of each student's part compared to the nominal dimensions.

Dimension	Nominal (mm)	Tool	Measured Value (mm)	Percent Difference
ØA	25.00	Bore Micrometer English - Convert to mm)		
ØB	11.00	Bore Micrometer		
ØC1	15.00	Bore Micrometer		
ØC2	15.00	Vernier Caliper Loc 1		
	15.00	Vernier Caliper Loc 2		
ØD	30.00	Bore Micrometer		
ØE	18.00	Bore Micrometer		
F	15.00	Vernier Caliper		
G	35.00	Depth Micrometer		
ØH1	18.00	Bore Micrometer		
ØH2	18.00	Vernier Caliper Loc 1		
	18.00	Vernier Caliper Loc 2		
I	60.00	Outside Micrometer		
J	12.00	Outside Micrometer		
K	30.00	Digital Caliper		
L	10.00	Inside Micrometer		
M	85.00	Vernier Caliper		
N1	14.00	CMM		
N2	14.00	CMM		
P	46.00	CMM		
Q1	15.00	CMM		
Q2	15.00	CMM		
R	15.00	CMM		
S	21.00	CMM		
T	12.00	Depth Micrometer		
U	45.90	Digital Protractor		

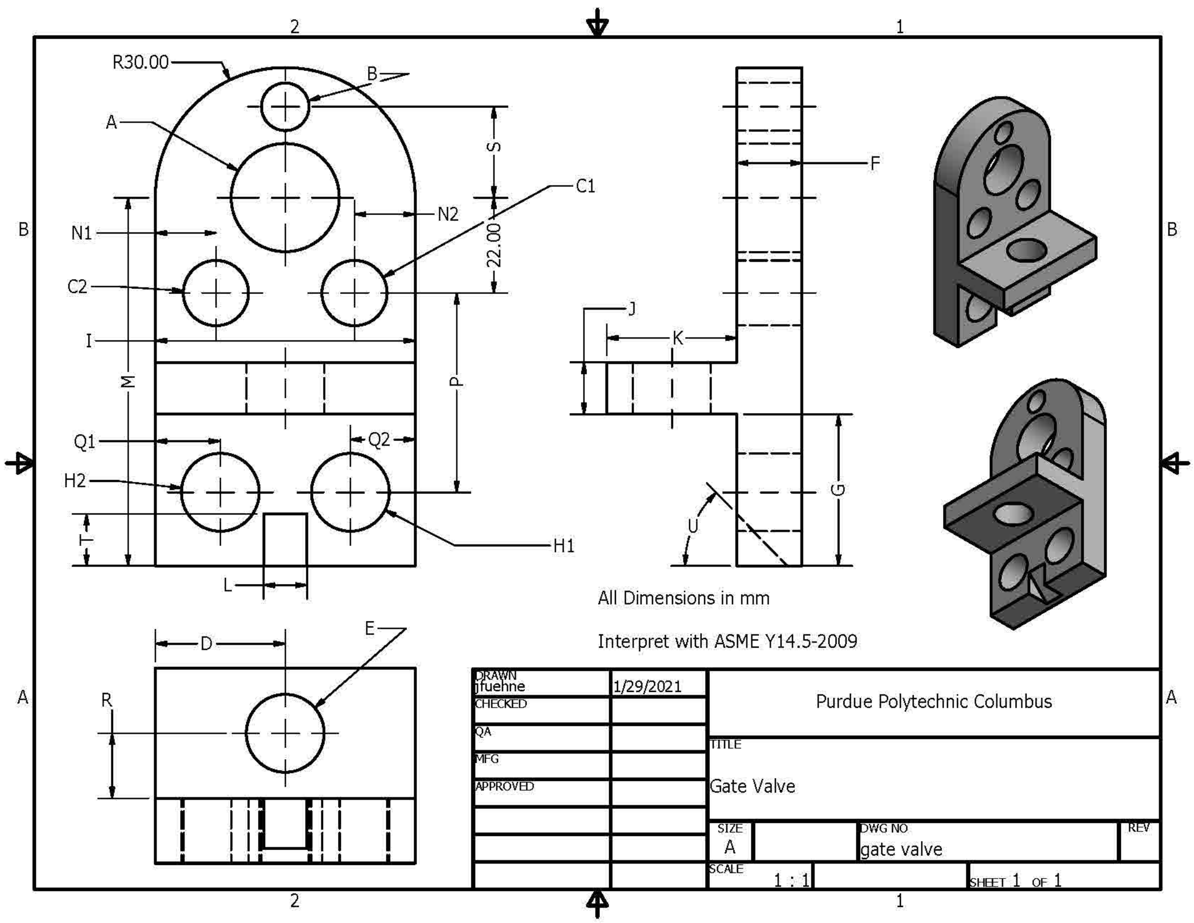

Figure 3. Drawing of the part indicating dimensions to measure using letters. Each student has their own 3D printed part.

are to pay attention to the contact pressure between the tool and the part during the measurement process. With the bore micrometers, a ratchet mechanism allows the user to apply relatively uniform pressure on each measured part/dimension. Vernier calipers, however, do not have this ratchet mechanism and are therefore subject to the technique of the operator, who must develop a “feel” for how to consistently use the caliper. Developing this is challenging, allowing students to understand the errors involved in various tools. Bending of the tool is also an issue with calipers and depends on the contact pressure applied between the part and the tool. There is no way for students/operators to acquire this ability other than making frequent measurements with the various tools. Other works by the author [3], [4], further explain these concepts that are based on the “Learning Pyramid” from the National Training Laboratories that students retain 75% of the knowledge when they “practice doing” rather than simply listening or watching videos.

Conclusions

The role of instructor in the current learning environment has changed from one of basically informing students to one of asking questions of students to initiate their own learning. The use of measurement tools in a manufacturing environment is critical and students headed for careers in that environment need to understand this critical role. And understanding comes from not only learning how to use the tools but also developing knowledge through the aforementioned coaching by instructors to learn which tool is best for each application. Certainly, questions surrounding the ability and/or necessary training of production workers, the desired efficiency of the measurement operation to support production, and the accuracy, precision, and uncertainty required of the measurement drive the selection of measurement tools. And it is critical that manufacturing engineers supervising and managing production lines need to be aware of the details and features of various measurement tools. This work aims to get beginning students in their first semester of college classes an introduction to many of these measurement tools as well as to the critical thinking required to utilize these tools in a manufacturing environment. These topics and skills are likely covered in engineering technology programs but not in traditional engineering programs.

References

[1] S. Stahley, S. Bhatty, C. Kincaid, D. Fant, J. Fuehne, and M. Bridgeman, "Advanced Center for Manufacturing Excellence Learning Lab," *Proceedings of the NCSL International Workshop and Symposium*, *Sacramento, CA, 2012*.

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[4] J. Fuehne, Training with Various Tools to Facilitate Measurement Instrument Selection, *metrologist: NCSLI Worldwide News,* Volume 14, Number 1, 2021, pp 76-85.